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硕　士　学　位　论　文

电液动力喷印微弱电流测试技术

Weak Current Detection Technique for Electrohydrodynamic Printing

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摘 要

电液动力耦合驱动微喷印，作为一种新兴的按需喷墨打印方法，成为下一代超精微流体喷射、亚微米电子制造潜在的优势技术。然而由于该项技术在微观机理上还未有完善明确的理论解释，在实际应用中缺乏系统的规律总结，因此急需开展相应的测试技术手段对其做进一步的探索。鉴于目前电液动力微喷印光学测试技术存在效率低、光学检测系统昂贵、无法实现流体喷印的实时在线检测；以及针对电液动力微喷印的电学性能测试技术还未有更多的研究，现存检测方法精度和灵敏度满足不了锥体射流模式下微弱信号的测试要求，导致无法从电学检测角度获得微喷印状态信息以开展射流动力学行为规律研究的缺陷，论文开展了如下研究工作：

(1) 根据荷电液滴产生的电流信号能反映液滴状态信息的机理，提出设计微弱电流信号测试系统，以满足锥体射流时液滴微弱电流的高精度、高灵敏度检测，进而从微喷印电流测试角度出发研究电液动力喷印的行为规律，得到液滴参数与喷印实验参数之间的规律性关系。

(2) 确定了微液滴携带极限电荷时以及喷印状态为连续射流束时的电流幅值，其范围为 30nA～3μA。结合低噪声设计处理工艺，最大限度的提高信噪比，分别针对 30nA～250nA 和 250nA～3μA 的微弱喷印电流设计两块 $I-V$ 测试信号调理电路板，相应实现了-20mV/nA 的微弱信号放大能力以及最高灵敏度为-10mV/nA 的微弱信号放大能力。

(3) 基于数据采集卡的硬件驱动原理和软件驱动函数，设计了基于虚拟仪器技术的高速数据采集程序，同时设计了相应的频谱测量程序、脉冲波形数值积分程序、电流幅值与重复一致性分析程序，实现了微喷印液滴的喷射频率及平均体积的实时检测，并于实验后期通过数据的快速处理获得了液滴的荷电量、重复一致性。

(4) 基于开发的电液动力喷印微弱电流测试虚拟仪器系统，对四种微喷印方式(即空芯喷头施加直流高压、实芯喷头施加直流高压、空芯喷头施加脉冲高压、实芯喷头施加脉冲高压)，分别进行流体锥射流动力学规律研究，获得了各

种微喷印方式中液滴喷射频率、液滴体积、液滴荷电量、重复一致性与喷射实验参数存在的可控规律性联系。

关键词：电液动力微喷印；微弱电流；测试技术；
信号采集分析；喷印行为规律

Abstract

Electrohydrodynamic Printing (EHDP), as a novel drop-on-demand ink-jet printing method, has become one of the most advantageous technologies for next-generation of Ultra-precision fluid jetting and sub-micron electronics manufacturing. However, the existing theories of micro-mechanism are still ambiguous in interpretating the liquid ejection by electrostatic driving, and laws of droplet ejection behavior on the application are also lack of systematic summary. Therefore, for further research on EHDP, more detection techniques should be immediately developed. Nevertheless, most investigations based on optical testing techniques for EHDP are inefficient, high cost, inability of real-time. At the same time, only a few researches have been carried out on the electrical properties for EHDP. The existing detection method does not fulfill the testing accuracy and sensitivity requirement of weak signals for the cone-jet mode of the EHDP. Accordingly, it is impossible to obtain the EHD droplet ejection state from the electrical testing, and investigation on the dynamical laws of EHDP from the electrical testing has been confined. To tackle these problems, this paper develops some programs by conducting the following research:

(1) According to the droplet ejection situation from the current signal of charged droplets, a weak current signal detection system was designed to meet the demands of high accuracy and sensitivity of the EHD cone-jet mode. Following that, the dynamical laws of EHDP from the current information were studied and the related regularity of droplet parameters to experiment parameters was obtained.

(2) The magnitude of current was calculated by analysing limited charge of the droplets and the jetting beams of EHDP, and the results showed the current ranged from 30nA to 3μA. Associated with low noise processing and for the sake of increasing SNR to a highest extent, the weak current detection circuits were devised for the magnitudes of 30nA～250nA and 250nA～3μA, respectively. Correspondingly, the amplification of weak current signal was realized with the sensitivity of

-20mV/nA and -10mV/nA(full-scale sensitivity) respectively.

(3) High-speed data acquisition program has been designed by Virtual Instrument Technology based on the hardware driving principle and software driving function of DAQ card. Programs for spectrum frequency measurement, pulse shape numerical integration, current magnitude and the repeated consistency analysis were also designed. The ejection droplet frequency and average volume of droplet were realized by a real-time observation during EHD jetting, meanwhile the droplet charge and repeated consistency were calculated via a rapid data processing method.

(4) Based on the weak current detection virtual instrument for EHDP system, we investigated the dynamical law of fluidic cone-jetting for the capillary-type nozzle with DC high voltage, needle-type nozzle with DC high voltage, capillary-type nozzle with high-voltage impulse and needle-type nozzle with high-voltage impulse. The results show that there are Controllable relationships between EHD ejection droplet frequency, droplet volume, droplet charge, jet repeated consistency and the experiment parameters.

Key words: Electrohydrodynamic printing; Weak current; Detection technique; Data acquisition for signal analysis; Behavior of EHD jet

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